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Departmental Report

A SURVEY AND COMPARISON OF CRITERIA FOR NAVAL MISSIONS

by

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DTRC/SHD-1312-01 A Survey and Comparison of Criteria for Naval Missions

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This report lists which motions and events are commonly thought to limit ship operations. Criteria sets for various Naval Missions are given along with their derivation. An annotated list of related literature is also included.

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NOMENCLATURE

AAW	Anti-Air Warfare
ARW	Air Warfare
ASW	Anti-Submarine Warfare
Br	Bridge
CAC	Command and Control
CG	Center of Gravity
CIC	Command Information Center
CL	Conventional Landing
CONREP	Connected Replenishment
CTO	Conventional Take-Off
CTOL	Conventional Take-Off and Landing
FAS	Fueling Along Side
FP	Forward Perpendicular
FSO	Fleet Support Operations
LFE	Lateral Force Estimator
L_{pp}	Length between perpendiculars
MII	Motion Induced Interruptions
N	Number of oscillations of irregular motion.
RAST	Recovery Assist Securing and Traverse System
SL	Short Landing
SSA	Significant Single Amplitude
STO	Short Take-Off
STOL	Short Take-Off and Landing
STREAM	Standard Tensioned Replenishment Alongside Method
SUW	Surface Warfare
T_0	Average period of vertical motion of a ship relative to ground.
T_n	Average period of vertical motion relative to the sea surface at Station n which is at $5(n\text{-}1)$ percent of length abaft the forward perpendicular.
UNREP	Underway Replenishment
V_{th}	Slamming threshold velocity
VERTREP	Vertical Replenishment
VL	Vertical Landing
VLS	Vertical Launch System
VTO	Vertical Take-Off
VTOL	Vertical Take-Off and Landing

ABSTRACT

This report lists which motions and events are commonly thought to limit ship operations. Criteria sets for various Naval missions are given along with their derivation. An annotated list of related literature is also included.

ADMINISTRATIVE INFORMATION

This investigation was sponsored by the Chief of Naval Research, Office of Naval Technology, Code ONT21, under the 6.2 Surface Ship Technology Program (ND1A), Program Element 62121N, Northern Latitudes Project RH21S23, Task 3, Ship Motion Control. The work was performed at the David Taylor Research Center during FY1989 under work unit number 1-1506-920. The DN number is 178067.

INTRODUCTION

The motions of a ship in a seaway can be easily determined using modern strip-theory motion programs, such as the Standard Ship Motion Program (SMP84)[1,2]. Subsequent work by McCreight and Stahl[3] incorporate environmental data with strip theory motion predictions to calculate Percent Time of Operability (PTO). Calculated PTO values depend very heavily upon the motion criteria used to specify thresholds of unacceptable motion. A significant problem may exist when PTO computations are required because it is difficult to determine the types and magnitudes of acceptable motions for a given ship mission. Furthermore, motion limiting criteria, when specified in open literature, are not always uniformly defined.

Degradations in operability can range from mild cases of motion sickness among crew members to severe restrictions on equipment capability. Ship performance degradations arise from habitability, equipment operability, and ship survivability considerations. Habitability refers to crew comfort and personnel requirements. Equipment operability refers to the specific motion limits which affect the operational capability of an individual piece of equipment or machinery system. Survivability is the ability of a ship to survive intact under severe sea conditions. Typically, the motion limits for ship survivability are high enough not to become a limiting factor in day to day operations.

All ships perform at least one primary mission i.e. shipping, fishing, anti-submarine patrol, etc., and possibly other secondary missions. The ability of the ship to perform each of its missions is assumed to be subject to motion limits, such that if a threshold is exceeded for a specified motion or combination of motions, the mission can no longer be effectively performed. No gradual degradation is presently accounted for in the PTO calculation. The criteria given are used in a strictly pass-fail manner. An attempt at gradual degradation can be made by choosing the pass-fail criteria to represent a predetermined level of degradation. The motion limit combinations which define ship mission limits are called criteria sets.

This report lists motions which are considered to limit operability for particular ship missions and why. A survey of various motion criteria, found in open literature, have been combined into coherent motion criteria sets for various Naval missions. The present approach to defining criteria and choosing limits, was to find the limiting criteria for the subsystems required for a certain mission, and then to overlay the respective subsystem limits to find the lowest common denominator. An annotated source list is provided, so the reader can determine the origin of the criteria and ensure that it is valid for a particular situation. The authors, papers, suggested criteria, and limits are presented in Table 1. This table shows the range of currently accepted seakeeping limits.

CRITERIA

The criteria typically used to determine the operability of a ship are: roll, pitch, slamming, deck wetness, absolute vertical displacement, velocity, and acceleration, lateral acceleration, Lateral Force Estimator, propeller racing, and sonar dome emergences. These criteria will summarized in the following paragraphs.

ROLL: Rolling may seriously affect crew comfort and performance. Roll is a rough measure of the acceleration parallel to the deck which causes personnel to lose balance. Moderate roll angles can cause loss of pallet control. Large roll angles reduce personnel effectiveness as crew members spend time holding on to the ship to maintain balance, instead of working. Very large roll angles can affect the

operation of radar systems and missile launching. Roll is often a limiting criterion at low speeds and beam to following seas. The roll criterion for the transit mission is 8° significant single amplitude (SSA)*.

PITCH: Pitch can also be a measure of crew habitability and operability, particularly in the forward and after portions of the ship, as a source of vertical acceleration. Large pitch angles can lead to slamming. Pitch is usually a limiting criterion at low speeds in head seas and all speeds in following seas. The limiting value for the transit missions is 3° SSA.

SLAMMING: Slamming can be defined in terms of flare, side, bottom, or cross deck slamming. SWATHs, catamarans, SES, and ACV are subject to cross deck slamming which occurs when a wave impacts the underside of the structure which connects the twin hulls. On conventional monohulls, bottom slamming is typically used as a criterion. A bottom slam is often defined as keel emergence at $0.15L_{pp}$ with a subsequent re-entry velocity greater than a given threshold velocity. The purpose of slamming as a criterion, is to limit structural damage to the hull and to limit shock induced vibration to ship systems. Fear of such consequences leads to voluntary reductions in speed as well. Slamming is usually a limiting criterion at high speeds for head seas. Typically 20 slams per hour is used as the maximum allowable for all non-urgent† missions.

DECK WETNESS: Deck wetness defines the passage of green water over the forward perpendicular. To date, no precise method of calculating bow spray exists. The drier the ship, in terms of wetness, the safer it is to conduct activity on the forward deck. Wetness as a limiting criterion is indicative of low freeboard, because most ships with adequate freeboard reach the slam limit before the wetness limit. Thirty (30) occurrences per hour of deck wetness is an accepted upper limit for all non-urgent missions.

*Significant single amplitude is the average of the 1/3 highest amplitudes.

†Non-urgent refers to peacetime or non-critical missions. Urgent refers to wartime or critical missions.

ABSOLUTE VERTICAL DISPLACEMENT: This criterion is a measure of the distance the ship moves vertically with respect to a fixed, i.e., not ship-wave, reference frame. Absolute Vertical Displacement is an important air operations criterion for conventional take-off/landing aircraft and helicopters. The magnitude of the displacement depends on the location on the ship at which it is calculated. The limiting value is unique for each type and model of aircraft.

ABSOLUTE VERTICAL VELOCITY: This criterion is the ship velocity vertically with respect to a fixed, i.e., not ship-wave, reference frame. Absolute Vertical Velocity is used as an air operations criterion for all aircraft and helicopter take-off/landing operations. The magnitude of the velocity depends on the location on the ship at which it is calculated. The limiting value is determined by the type and model of aircraft used.

ABSOLUTE VERTICAL ACCELERATION: Absolute Vertical Acceleration is the ship acceleration vertically with respect to a fixed, i.e., not ship-wave, reference frame. It is a measure of crew comfort and is usually measured at the bridge or forward perpendicular. Computations made for the forward perpendicular provide an overall level of Absolute Vertical Acceleration for comparisons sake. Absolute Vertical Acceleration could be used as a criterion in any significant manned spaces,e.g. crew quarters, pilot house. Absolute Vertical Acceleration calculations made in important manned spaces could then be weighted and averaged over the entire length of the ship[4] to find an overall value. It is often a limiting criterion at high speeds. The typical limiting value at the bridge is 0.4 g SSA and at the forward perpendicular is 0.55 g SSA.

ABSOLUTE LATERAL ACCELERATION: Absolute Lateral Acceleration is the ship acceleration laterally with respect to a fixed, i.e., not ship-wave, reference frame. It is a measure of crew comfort and typically measured at the bridge. It is rarely a limiting criterion and usually ignored. The usual limiting value is 0.20 g SSA at the bridge.

RELATIVE MOTION: This is the distance between a specified point on the ship and the wave surface. The deployment and recovery of towed arrays or cranes reaching over the side use relative motion as a criterion. The launching of amphibious assault craft is also subject to relative motion limits. Assault craft have to be able to enter and exit the well deck through an opening whose size depends on the relative motion between the wave and the well top. The amount of relative motion is location dependent. The limit is determined by the application.

PROPELLER RACING: Propeller racing is defined by Lloyd and Andrew[5] to occur during the emergence of a portion of the propeller equal to one fourth of the propeller diameter. It is included as a criterion to prevent excessive machinery wear, vibration, and avoid a possible noise source. Lloyd and Andrew suggest that between 90 and 120 excursions per hour would be tolerable.

SONAR DOME EMERGENCES: A sonar dome is said to be emerged when it is half out of the water. When the most forward point of the dome emerges from the water, it is safe to assume that half of the transducers in the bow sonar dome are out of the water, therefore this point was used to calculate emergences. The limits are determined by sonar type, active or passive mode of operation, acoustic frequency, and target range. In general, to be completely effective at 10 nautical miles, an active sonar needs fewer than 24 emergences per hour[6]. A passive sonar can tolerate 90 per hour[6]. The sonar dome emergence criterion is a limiting criterion for the same conditions as slamming.

LATERAL FORCE ESTIMATOR: Lateral Force Estimator (LFE) is a combination of the earth-referenced lateral acceleration, and the ship-referenced lateral acceleration due to roll. It can be correlated with Motion Induced Interruptions (MII)[7,8] which are a measure of how difficult it is to perform effective work on the ship. It is location dependent, and is typically it is calculated at the bridge, or helicopter platform where a value of 0.14 g's SSA is often used as the tolerable limit.

Similar to the LFE is what is referred to as subjective motion. This is not a physical motion, but rather a derived value based on oscillation tests of United States Air Force (USAF) pilots[5,9]. The pilots were asked to judge which frequencies and oscillation magnitude combinations were equivalent. This became the intensity other combinations were scaled to. No limiting values are presented.

ANNOTATED LIST OF SOURCES

1. Baitis, A.E., Applebee, T.R., and McNamara, T.M., "Human Factor Considerations Applied to Operations of the FFG-8 and LAMP Mk III"[7]

   This article deals specifically and in detail with the launch and recovery of the LAMP Mk III from the FFG-8 using RAST. The article considers how wind forces, MII, and LFE all relate to crew efficiency and safety. Different levels of risk are identified, and values of MII and LFE are associated with each. The given limiting values of LFE and MII for different levels of crew degradation and risk are valid for all ships.

2. Brown, D.K., "Seaworthy by Design"[8]

   This article discusses seakeeping performance of various British Navy ship classes with a combination of analytical analysis and performance reports. Brown argues that improved seakeeping will increase fleet effectiveness and that good seakeeping should be a major design objective. The use of Lateral Force Estimator is discussed as a criterion and correlated with Motion Induced Interuptions. The author lists some assumptions usually made in seakeeping assessments. Brown suggests making ships larger as the simplest solution to improving seakeeping.

3. Conolly, J.E., "Standards of Good Seakeeping for Destroyers and Frigates in Head Seas"[10]

   A method of comparing the seakeeping behavior of different ships is presented. The method is based on the event occurrence period and takes the form of graphs of maximum speed for a given sea state and criterion. The technique is correlated with full scale trials data of Dutch destroyers. The paper deals solely with

head seas and three criteria: keel slamming, deck wetness, and vertical acceleration. Different frequencies of limit exceedence are compared. The method can be extended to other headings and criterion.

4. Hadler, J.B. and Sarchin, T.H., "Seakeeping Criteria and Specifications"[11]

   Hadler and Sarchin interviewed Commanding Officers to find out what factors were limiting operations. Habitability, operability, and survivability of destroyers are discussed. This article states that criteria for changing speed and/or heading is not usually based on structural or mechanical limits, but rather on the Commanding Officer's judgment. Sample criteria for night and day helicopter operations are presented.

5. Karppinen, T., "Criteria for Seakeeping Performance Predictions"[12]

   Karppinen details the methodology of Seakeeping Performance Index calculations. He also discusses the applicability of the criteria sets used and their derivations. The paper deals mainly with merchant ships.

6. Kehoe, J. W., "Destroyer Seakeeping: Ours and Theirs"[13]

   This paper establishes the wetness criterion of one deck wetness per minute. Slam criterion of one bottom slam per minute is listed as the point where naval ships must reduce speed.

7. Lain, H., Daugard, S., Tomassoni, C., and Guilfoyle, J. "Motion Induced Degradation of Ship Subsystems"[6]

   The main reference for this report, it consists of chapters devoted to major ship subsystems, with motion limits, a brief discussion, and list of annotated sources for each subsystem. The criteria presented are vague as to whether the particular value is really significant or maximum. Generic air operations motion criteria and relative wind envelopes are given.

8. Lloyd, A.R.J.M. and Andrew, R.N., "Criteria for Ship Speed in Rough Weather"[5]

   Lloyd and Andrew cite slamming, deck wetting, motions, and propeller emergence as reasons for loss in ship speed. Proposed limits are based on full scale data of

three Dutch destroyers. Motion limiting criteria presented by other authors are discussed. Whipping vibration of hull girder is included as part of slam criterion. Formulae for calculating whipping acceleration and subjective motion are presented. Motion criteria can be weighted by personnel location and averaged along ship length.

9. NORDFORSK, "Assessment of Ship Performance in a Seaway"[4]

   This report discusses the concept of total ship criteria, not merely subsystem criteria. Roll, pitch, accelerations, slamming, deck wetting, and propeller racing are used as motion limiting criteria. The concept of calculating total ship operability as a weighted average of the operability of different points on the ship is presented. Each point,e.g., the bridge or forward perpendicular, has its own criteria set depending on what is being done at that point. Data is provided for both merchant and naval vessels of different sizes. Non-probabilistic criteria, such as, maneuvering, are also proposed.

10. Olson, S. R., "A Seakeeping Evaluation of Four Naval Monohulls and a 3,400 ton SWATH"[14]

    This paper analyzes the seakeeping of different hull forms. It gives wetness criteria based on personal experience. It briefly discusses gun systems and gives limits on SWATH cross section slamming and active sonar ping returns.

11. Shoenberger, R. W., "Subjective Response to Very Low Frequency Vibration"[9]

    USAF pilots were asked to judge the relative intensity of different amplitude and frequency combinations. The intensities were then scaled and curve fitted to form the basis for subjective motion.

12. Walden, D.A. and Kopp, P., "DDG51 Contract Design Comparative Seakeeping"[15]

    This report re-evaluates and verifies earlier seakeeping criteria for various naval missions. The criteria are applied specifically to the DDG51 contract variants. The rational behind the criteria is explored.

CRITERIA SETS BY MISSION

The following is a summary of the criteria sets for different missions to be carried out by Navy ships, as derived from Lain, et al.[6] and Walden and Kopp[15]. The mission sets deal only with subsystems essential to that mission which are above and beyond the Mobility criteria set. The MISSION CRITERIA SETs are the combination of the lowest motion values of the subsystem criteria sets. Table 2 summarizes the mission criteria sets. The subsystem criteria sets are presented after the mission criteria set to allow the ship designer to make modifications to suit special circumstances. The limits for the subsystem criteria were taken from Lain, et al., except where otherwise noted. The actual criteria sets used in a seakeeping evaluation would be the lowest criteria value for the combination of the Mobility mission and a given mission criteria set, see Table 3. Unless otherwise noted, the limits are significant single amplitude[‡].

MOBILITY (MOB)

The mobility mission, also referred to as the transit mission, is simply a measure of whether the ship can make point to point transits at sea. The PERSONNEL limits were taken from Walden and Kopp[15].

MOBILITY MISSION CRITERIA SET			
	Roll	8°	CG
	Pitch	3°	CG
	Vert Accel	0.4 g	Pilot House
	Lat Accel	0.2 g	Pilot House
	SLAMS	20/hr	Bottom
	DECK WET	30/hr	Foredeck
PERSONNEL	Roll	8°	
	Pitch	3°	
	Vert Accel	0.4 g	Pilot house
	Lat Accel	0.2 g	Pilot house

‡Maximum single amplitude limits were considered the average of the 1/100 highest values and can then be converted to significant values by multiplying by 0.597015, see Reference 16.

SLAMS	Non-urgent	20/hr	0.15Lpp aft FP, $V_{th} = 0.093\sqrt{gLpp}$
	Urgent	60/hr	
DECK WETNESS	Non-urgent	30/hr	Foredeck
	Urgent	60/hr	Foredeck
		5/hr	Elevator
MACHINERY	Roll	27°	
	Pitch	6°	
CRANES	Roll	6°	Navy 100% efficiency

COMMAND AND CONTROL (CAC)

The Command and Control mission involves the gathering of information by use of radar and sonar for coordination and control of self and other forces.

COMMAND AND CONTROL MISSION CRITERIA SET

	Roll	15°	CG
	Pitch	6°	CG
	Active Sonar	24/hr	Emergences
SONAR DOME	Roll	18°	
	Pitch	6°	
	Active	24/hr	Emergences
	Passive	90/hr	Emergences
RADAR	Roll	15°	100% efficiency

AIR WARFARE (ARW)

Motion limiting criteria relating to Air Warfare centers around the launch and recovery of aircraft. The criteria set for ARW is the lowest values of the combination of the PERSONNEL criteria, the aircraft criteria, and the relative wind envelope. In virtually all cases, the criteria are determined by the aircraft limitations. The actual criteria and relative wind envelope used depend on the type of aircraft to be launched and recovered. Generic criteria can be found in Table 4 and the relative wind envelopes in Figs. 1-3.

ANTI-AIR WARFARE (AAW)

The anti-air warfare mission sub-systems which can be degraded by ship motion are those necessary to track and shoot down enemy aircraft; i.e., radar, missiles, and vertical launch system. This criteria set is for launching/handling, not strikedown. It does not include period, yaw or longitudinal accelerations criteria.

ANTI-AIR WARFARE MISSION CRITERIA SET			
	Roll	6°	
	Pitch	4°	
	Vert Accel	1.3 g	
	Lat Accel	0.8 g	
RADAR	Roll	15°	
MISSILE (NON VLS)	Launcher	9°	Roll/Pitch
	Auto Handling	9°	Roll/Pitch
	Man Handling	6°	Roll/Pitch
	Strikedown	3°	Roll/Pitch
VLS	Roll	21°	9 sec period maximum
	Pitch	4°	9 sec period maximum
	Yaw	2°	6 sec period maximum
	Vert Accel	1.3 g	
	Lat Accel	0.8 g	
	Long Accel	0.3 g	

ANTI-SUBMARINE WARFARE (ASW)

This mission involves surface combatants operating against submarines. In addition to towed sonar arrays, submarines can be detected by use of hull borne sonar or anti-submarine helicopter patrols. The helicopter patrols are limited by aircraft constraints and are considered part of ARW. Hull borne sonars must remain submerged to be effective. For this mission, the sonar dome criteria set is the mission criteria set.

ANTI-SUBMARINE MISSION CRITERIA SET			
SONAR DOME	Roll	18°	
	Pitch	6°	
	Active	24/hr	Emergences
	Passive	90/hr	Emergences

SURFACE WARFARE (SUW)

The surface warfare mission is surface ships against surface or land targets. The subsystems necessary are those needed to track and destroy surface targets; i.e., radar, missiles, and guns. The absolute vertical velocity limit at gun mount determined from Walden and Kopp[15].

SURFACE WARFARE MISSION CRITERIA SET

Roll	6°	Man handling
Pitch	4°	
Abs Vert Accel	1.3 g	
Abs Lat Accel	0.8 g	
Abs Vert Vel	3 ft/sec	Gun Mount

RADAR	Roll	15°	
MISSILE (NON VLS)	Launcher	9°	Roll/Pitch
	Auto Handling	9°	Roll/Pitch
	Man Handling	6°	Roll/Pitch
	Strikedown	3°	Roll/Pitch
VLS	Roll	21°	9 sec period maximum
	Pitch	4°	9 sec period maximum
	Yaw	2°	6 sec period maximum
	Vert Accel	1.3 g	
	Lat Accel	0.8 g	
	Long Accel	0.3 g	
GUNS	Roll	9°	
	Pitch	9°	
	Abs Vert Vel	3 ft/sec	DDG51 criteria

FLEET SUPPORT OPERATIONS (FSO)

Fleet Support Operations, also known as underway replenishment, consist of 3 different replenishment missions: CONnected REPlenishment (CONREP), VERTical REPlenishment (VERTREP), and Fueling Along Side (FAS). In addition to simply moving stores from one ship to another, there is missile handling and VLS strikedown. A generic UNREP mission criteria will be given that is the lowest values of all three missions. If a ship is to be evaluated for a specific mission, then the specific mission criteria set

should be used. To judge FAS operations, the FAS criteria should be used rather than the generic set which includes VLS strikedown and pallet control. When conducting VERTREP, only the supply ship need worry about helicopter launch and recovery operations and its limiting criteria (see ARW). The CONREP and FAS criteria are based on the STREAM system. The VLS strikedown limits are taken from Lain, et al.[6], but are interpreted as significant values instead of maximum values, per Walden and Kopp[15].

GENERIC UNREP MISSION CRITERIA SET

Roll	5°	Pallet control	8° max sin amp
Pitch	2°	Transfer equipment	3° max sin amp

CONREP	Roll	5°	Pallet control
	Pitch	2°	Transfer equipment
	Roll	6°	Missile handling
VERTREP	Roll	5°	Pallet control
FAS	Roll	6°	Transfer equipment
	Pitch	2°	Transfer equipment
VLS STRIKEDOWN	Roll	5°	
	Pitch	2°	

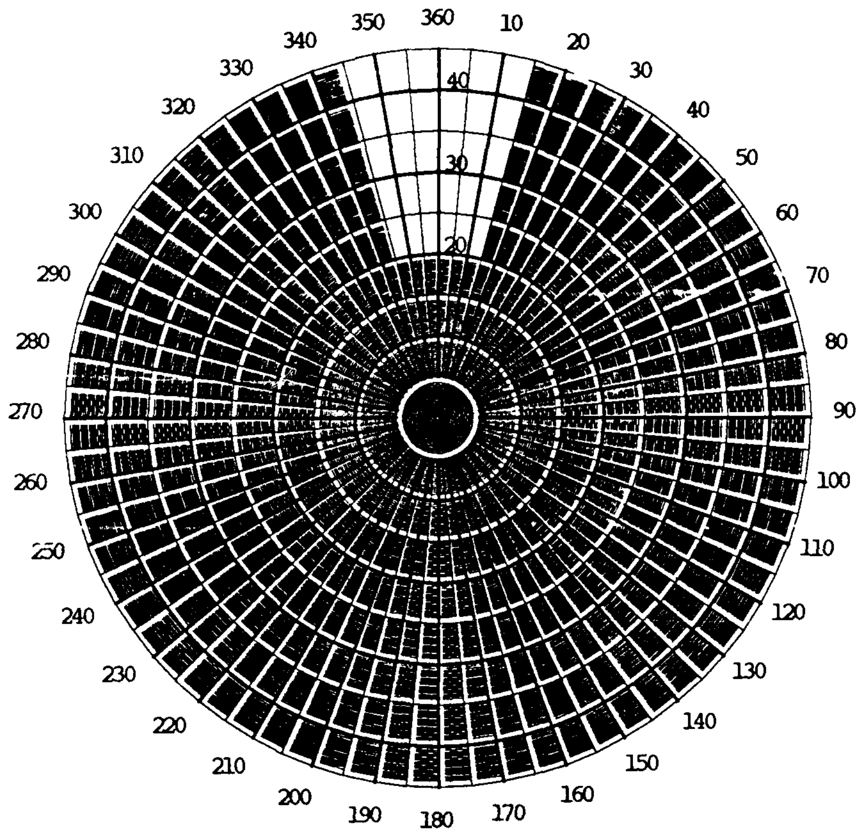
The criteria for the supply ship carrying out VERTREP has the above criteria superimposed on the helicopter operation criteria.

RECOMMENDATIONS

A systematic approach must be taken when establishing motion limiting criteria for a particular ship mission. The subsystems required for that mission, personnel, radar, missile loaders, etc., need to be identified. Then, the motion limits for 100% efficiency have to be determined. If another level of performance degradation is acceptable, then the motion limits should reflect the chosen level of performance. Once the pertinent subsystems and the motion limits have been identified, the "weakest link" in terms of ship motions can be found. This method of determining criteria sets allows motion limits to be set at an arbitrary level of degradation, identifies which activity or subsystem is most limiting for that mission and can be applied to any mission.

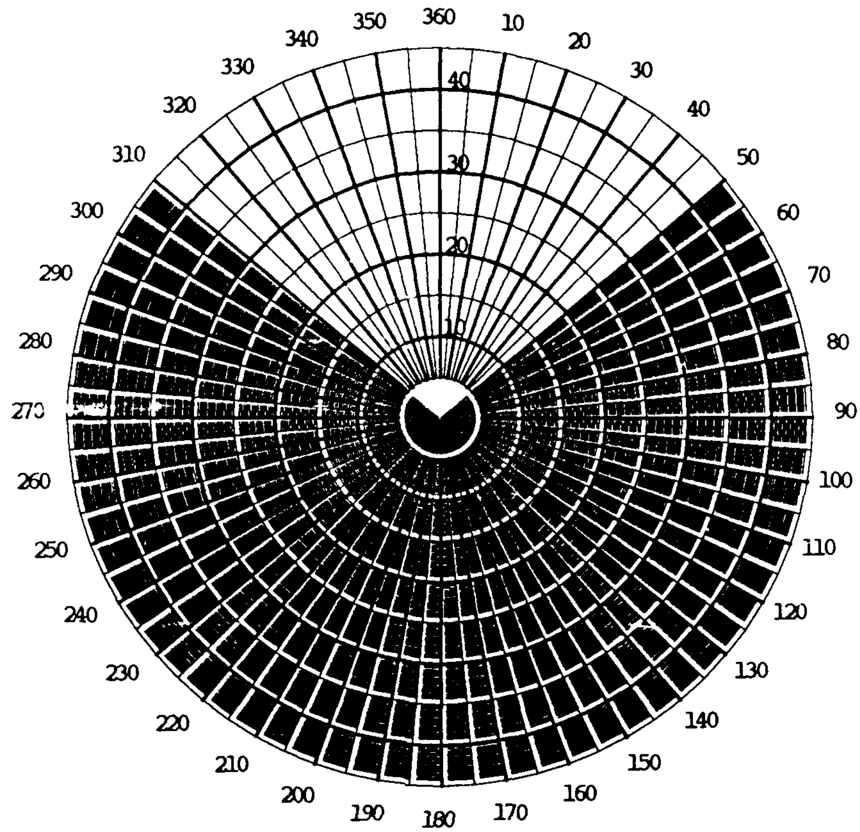
The suggested criteria sets are meant to be used in a generic sense to provide a reference to start the seakeeping design process. By using the same criteria sets for every ship, a realistic comparison can be made regarding the ability of each respective ship to perform an arbitrary mission. Whether or not a ship can perform the mission in reality, depends on how closely the criteria reflect the actual mission. As missions or system limits change, new criteria sets should be developed. The table of authors and their criteria give a flavor for variability in the subject matter. More than one author has mentioned that the criteria sets become invalid the instant the captain starts using his own judgment. However, by choosing the limits to reflect the tendencies of the average captain, criteria sets can be developed to closely model real world operability. This was done during full scale trials when interviews were conducted with crew members.

The development of new ship motion limits should continue so ship designers and strategic planners can use ship motion criteria to make global operability estimates with increased accuracy. Also ship motion limits are useful in defining safe operating envelopes for particular missions in real time computer programs, such as Tactical Decision Aids. Further validation of existing criteria will be of immediate benefit in this area.



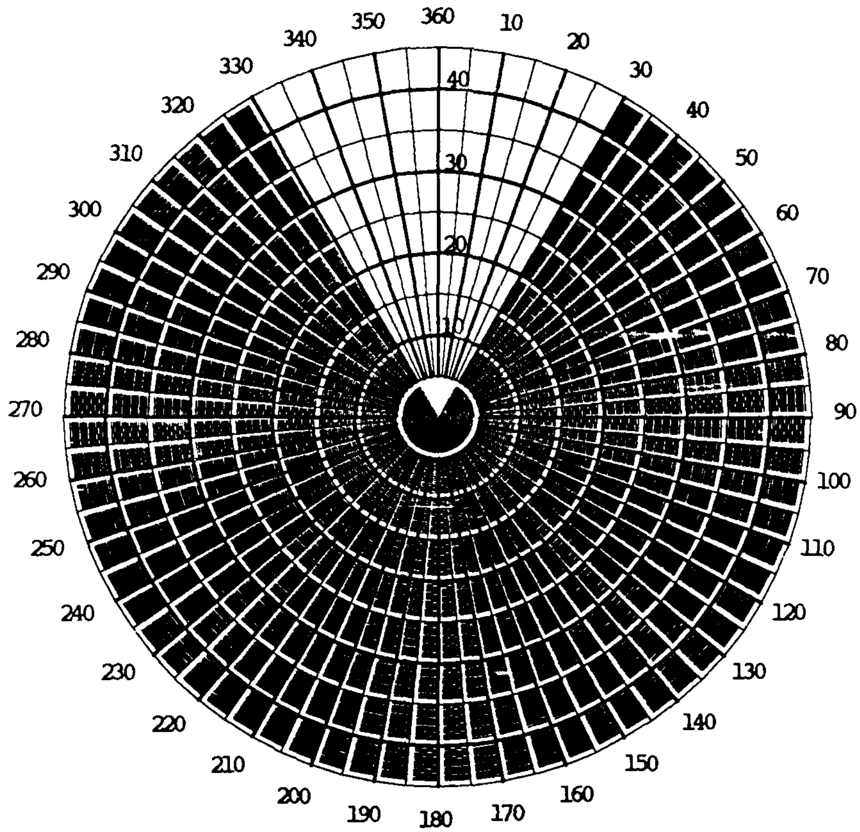
† Shaded areas indicate unacceptable wind conditions. Speed circles are in 5 knot increments.

Figure 1. Generic relative wind envelopes for CTO/L aircraft adapted from Reference 6.



† Shaded areas indicate unacceptable wind conditions. Speed circles are in 5 knot increments.

Figure 2. Generic relative wind envelopes for VTO/L aircraft adapted from Reference 6.



† Shaded areas indicate unacceptable wind conditions. Speed circles are in 5 knot increments.

Figure 3. Generic relative wind envelopes for STO/L aircraft adapted from Reference 6.

Table 1. Summary of literature search.

	Roll	Pitch	Slam	Wet	Vertical accel.	Lateral accel.	Sonar emergence	Propeller racing
'Seakeeping by Design' Brown[8] (Typical frigate.)			20/hr	30/hr			80/hr	
'Standards of Good Seakeeping for Destroyers and Frigates in head seas' Conolly[1]0 (Based on trials.)			$T_5N = 1360$ 1 slam@.2L every 1360s	$T_1N = 110$ 32/hr	$T_0N = 673$ 0.5g@.2L 1/673 1g@FP 1/673sec			
'Seakeeping Criteria and Specifications' Hadler & Sarchin [11] *	10°							
'Destroyer Seakeeping: Ours and theirs' Kehoe[13]			60/hr	60/hr				
'Motion Induced Degradation of Ship Subsystems' Lain, Daugard, Tomassin, Guilfoyle[6] †	10°	3°	20/hr 60/hr	30/hr 60/hr	0.4g B	0.2g B	24/hr active 90/hr passive	
'Criteria for Ship Speed in Rough Water' Lloyd & Andrew[5]				36/hr				90-120/hr
'Assessment of Ship Performance in Seaway' NORDFORSK[4] ‡	8°		Prob 0.03	Prob 0.05	0.55g FP 0.40g B	0.20g B		
'A Seakeeping Evaluation of 4 Naval Monohulls and a 3,400 ton SWATH' Olson[14]				30/hr				
'DDG51 Contract Design Comparative Seakeeping' Walden & Kopp[15] ‡	8°	3°	20/hr	30/hr	0.4g B	0.2g B	24/hr	

* These values are average single amplitude.
† These values are maximum single amplitude.
‡ These values are significant single amplitude.

Table 2. Summary of mission criteria sets.

	Roll deg	Pitch deg	Vert Acc g	Vert Vel ft/sec	Vert Disp ft	Lat Acc g	Slams per hr	Wetnesses per hr	Dome Emerg per hr
MOB	8	3	0.4			0.2	20	30	
CAC	15	6							24
ARW	*	*	0.4	*	*	0.2			
AAW[1]	6	4	1.3			0.8			
ASW	15	8							24
SUW[1]	6	4	1.3	3		0.8			
FSO	5	2							

Table 3. Summary of overlapped mission criteria sets.

	Roll deg	Pitch deg	Vert Acc g	Vert Vel ft/sec	Vert Disp ft	Lat Acc g	Slams per hr	Wetnesses per hr	Dome Emerg per hr
MOB	8	3	0.4			0.2	20	30	
CAC	8	3	0.4			0.2	20	30	24
ARW	*	*	0.4	*	*	0.2	20	30	
AAW[1]	6	3	0.4			0.2	20	30	
ASW	8	3	0.4			0.2	20	30	24
SUW[1]	6	3	0.4	3		0.2	20	30	
FSO	5	2	0.4			0.2	20	30	

* These values are aircraft dependent and are found in Table 4.

1 If missile handling is automatic instead of manual, the roll limit is 8°

NOTE: Roll and pitch values are significant single amplitude.

Table 4. Aircraft launch and recovery criteria adapted from Reference 6.

Aircraft Type	Motion	Significant Single Amplitude Limit	Location
Helicopter without RAST	Roll	6.4° (100% effective) 9.2° (0% effective)	CG CG
	Vertical Displacement	4.7 feet	Flight Deck
	Vertical Velocity	7.0 feet/sec	Flight Deck
	Relative Wind	(Helicopter Envelope)	
Helicopter with RAST	Roll	12° (100% effective) 17° (0% effective)	CG CG
	Relative Wind	(Helicopter Envelope)	
Generic CTO and CL	Roll	5°	CG
	Pitch	1°	CG
	Vertical Displacement	7.1 feet	Flight Deck
	Vertical Velocity	4.7 feet/sec	Touchdown Point
	Relative Wind	(Generic CTOL Envelope)	
Generic VTO and VL	Roll	5°	CG
	Pitch	3°	CG
	Vertical Velocity	6.5 feet/sec	Flight Deck
	Relative Wind	(Generic VTOL Envelope)	
Generic STO and SL	Roll	5°	CG
	Pitch	3°	CG
	Vertical Velocity	6.5 feet/sec	Takeoff Point
	Relative Wind	(Generic STOL Envelope)	

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